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Characterization of Vertical Deceleration Tower Plunger Profiles

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Air Force Research Laboratory

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Interim Report for April 2004 to May 2004

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Biomechanics Branch
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14. ABSTRACT

Tests were run on the AFRL/HEPA Vertical Deceleration Tower (VDT) to document the dynamic response of twelve available plungers. The standard seat fixture was used with an ACES II ejection seat seat pan and seat back. A 50th percentile HYBRID 3 manikin restrained with a PCU-16P harness was used for all tests. Data collected were Carriage X, Y, and Z acceleration. Processed data included impact rise time, impact duration, velocity change, and onset rate. These characteristics were documented for Carriage Z axis accelerations of 6G, 8G, 10G, 12G, 15G, and 20G.

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Vertical Deceleration Tower, VDT, plunger, acceleration, rise time, pulse duration, onset rate, velocity change

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PREFACE

An experimental effort was conducted to determine and document the dynamic response characteristics of the 12 plungers currently available for use on the Vertical Deceleration Tower. Characteristics documented in this report include impact rise time, impact duration, velocity change, Carriage X acceleration, Carriage Y acceleration, Carriage Z acceleration, and onset rate. These characteristics are documented for Carriage Z axis accelerations of 6G, 8G, 10G, 12G, 15G and 20G.

The tests described within this report were accomplished by the Biomechanics Branch, Biosciences and Protection Division, Human Effectiveness Directorate of the Air Force Research Laboratory (AFRL/HEPA) at Wright-Patterson AFB, Ohio.

The impact facilities, data acquisition equipment, and data processing system were operated by General Dynamics under ALSTAR Contract FA8650-04-D-6472.

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INTRODUCTION

Background

The Vertical Deceleration Tower (VDT) plunger operating characteristics were first documented in 1976 in the form of two graphs: one depicting peak G level obtained versus velocity change and the other depicting onset rate versus velocity change. These curves did not include all available plungers and were not accurate for all plungers and all peak velocities.

Later in the 1990's a study was conducted that re-examined the operating characteristics of the VDT. New curves were generated in the form of two graphs of the same parameters as the 1976 graphs. Again, not all the plungers were tested and the graphs were only approximations. No report was prepared documenting this work, limiting its usefulness.

Plunger 102, which provides an acceleration profile approximating that of an ejection seat, is the one most frequently used on the VDT. This plunger's response is well represented in the Biodynamics Data Bank (a web-based repository of data collected on each VDT test), but that of others is not.

Test Objectives

The specific objective of this study is to determine and document the operating characteristics for each of twelve available plungers at commonly used acceleration levels.

The operating characteristics documented for each plunger at acceleration levels of 6G, 8G, 10G, 12G, 15G and 20G include drop height, velocity change, rise time, pulse duration, and onset rate.

METHODS

Test Facilities and Equipment

The Vertical Deceleration Tower (see Figure 1) was used for all tests. The VDT consists of a 60-foot vertical steel tower which supports a guide rail system, an impact carriage supporting a plunger, a hydraulic deceleration device and a test control and safety system. The carriage can be raised to a maximum height of 42 feet prior to release. In this study maximum drop height was restricted to less than about 30 feet due to whip cable (the cable connecting the data acquisition system on the carriage with the instrumentation room) limitations. Twenty G's was the maximum acceleration level tested both because that is the upper limit for the camera mount attached to the carriage and because of the limited use of higher acceleration levels.

In a test, the carriage is hoisted up the tower by a winch to a predetermined height and then released. The carriage free falls until the plunger, attached to the bottom of the carriage, enters a water-filled cylinder mounted at the base of the tower. The deceleration profile, produced as the plunger displaces the water in the cylinder, is determined by the free-fall distance, the carriage and test specimen mass, the shape of the plunger, and the size of the cylinder orifice.

The test specimen used for this study was the standard Vertical Impact Protection (VIP) seat fixture to which was attached the seat pan and back of an ACES II ejection seat and a Hybrid III 50^{th} percentile manikin weighing 167 pounds (see Figure 2). The seat back and pan used have very nearly the same weight as the standard wooden seat back and seat pan commonly used on the VIP seat. The 50^{th} percentile Hybrid III manikin used was selected to be of a weight at the approximate midpoint of the range of manikin weights commonly used.

Figure 1: Vertical Deceleration Tower

Figure 2: Seat and Manikin

Instrumentation and Data Processing

The only instrumentation used in the tests was a triaxial accelerometer mounted to the carriage. The right-hand coordinate system shown in Figure 3 was used for all tests. Transducer signal processing, including excitation, amplification, filtering, and transmission, was provided onboard the VDT carriage by the DTS TDAS Pro Data Acquisition System. Sampling for all channels was at 1,000 samples per second, except for all tests with Plunger 108, which used 2,000 samples per second. All channels were filtered at 120 Hz, except for all tests with Plunger 108, which were filtered at 300 Hz. The higher cutoff frequency and sampling rate were used for this plunger to ensure accurate data collection at the very high onset rate. All filtering was done with a five-pole Butterworth filter.

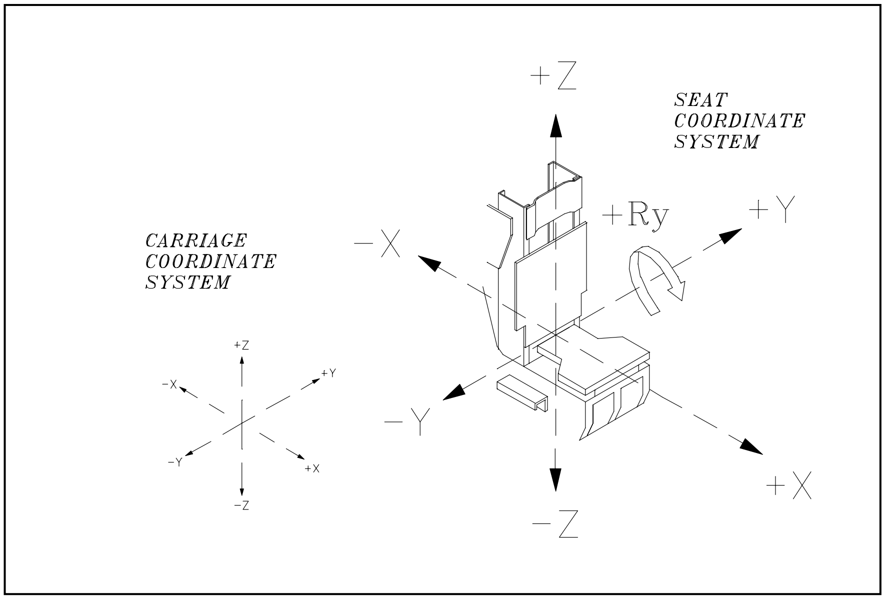

Figure 3: VDT Coordinate System

Experimental Design

Table 1 shows the test matrix used for this test program. Each cell was repeated until the desired acceleration level was achieved +/-2%. Due to time constraints a few cells were accepted as complete with a peak acceleration level slightly out of tolerance. In particular, tests with plunger 108 could not be kept within these tolerances due to the extremely high onset rate (see page 36 in Appendix A for an example). For those cells with a peak acceleration out of tolerance, the actual acceleration level is shown next to the drop height in Table 3.

Table 1: Test Matrix

			G LEVEL			
PLUNGER	6G	8G	10G	12G	15G	20G
18	A1	A2	A3	A4	A5	A6
30	B1	B2	B3	B4	B5	B6
46	C1	C2	C3	C4	C5	C6
100	D1	D2	D3	D4	D5	D6
101	E1	E2	E3	E4	E5	E6
102	F1	F2	F3	F4	F5	F6
103	G1	G2	G3	G4	G5	G6
104	H1	H2	H3	H4	H5	H6
105	I1	I2	I3	I4	I5	I6
106	J1	J2	J3	J4	J5	J6
107	K1	K2	K3	K4	K5	K6
108	L1	L2	L3	L4	L5	L6

RESULTS

VDT Test Numbers for Each Cell

Table 2 lists the VDT test numbers accepted as representative of the response of each plunger at each G level. Three cells have no test numbers: cells A6 and E6 because the required drop height was excessive, and cell L1 because the drop height would be less than zero (six G's could not be obtained even with the tip of the plunger touching the water). This table is useful when accessing the Biodynamics Data Bank (www.biodyn.wpafb.af.mil, study 200401) for test information. Appendix A of this report contains plots of the acceleration profiles for each plunger.

Table 2: VDT Test Numbers

PIN	CELL	6G	8G	10G	12G	15G	20G
18	A	4774	4777	4781	4782	4784	X
30	B	4786	4787	4788	4789	4791	4793
46	C	4740	4741	4742	4744	4745	4747
100	D	4750	4751	4752	4753	4754	4755
101	E	4728	4731	4733	4736	4737	X
102	F	4701	4702	4703	4704	4705	4706
103	G	4767	4768	4769	4770	4771	4772
104	H	4757	4759	4761	4763	4764	4765
105	I	4707	4708	4709	4710	4712	4714
106	J	4796	4797	4798	4800	4801	4802
107	K	4717	4719	4720	4722	4724	4725
108	L	X	4815	4806	4812	4810	4816

Drop Height Required to Achieve Desired Acceleration Level

Table 3 shows the drop height required to achieve the acceleration level desired in each cell. For a few cells, the acceleration achieved was outside the desired 2% tolerance band. The actual acceleration level (in G) achieved in these cases is shown in parentheses.

Table 3: Drop Height for Desired Peak Acceleration

PLUNGER	**6G**	**8G**	**10G**	**12G**	**15G**	**20G**
18	8' 7"	11' 9"	14' 8" (10.25G)	17' 0" (12.27G)	22' 5"	X
30	3' 5"	4' 10"	6' 1" (9.79G)	7' 10"	9' 8"	13' 5"
46	1' 10"	2' 7"	3' 6"	4' 4"	5' 6"	7' 4"
100	1' 8"	2' 9"	3' 11"	5' 1"	6' 9"	9' 6"
101	9' 11"	13' 10"	18' 0"	21' 5"	27' 6" (15.37G)	X
102	5' 6"	8' 5"	11' 6"	14' 6"	18' 6"	25' 5"
103	3' 6"	5' 6"	7' 5"	9' 1"	12' 0"	16' 5"
104	5' 3"	7' 3"	9' 9"	12' 1"	15' 5"	21' 0"
105	3' 6"	5' 0"	6' 6"	8' 3"	10' 6"	13' 11"
106	2' 1"	4' 1"	5' 5"	6' 9"	8' 9"	11' 10"
107	2' 0"	2' 10"	3' 9"	4' 8"	6' 0"	8' 0"
108*	X	0' 0" (8.35G)	0' 1" (9.44G)	0' 4"	0' 7"	0' 10" (18.48G)

*A zero drop height means the tip of the plunger is just touching the water at carriage release.

Onset Rate (G/sec) and Velocity Change (ft/sec) for Each Cell

The acceleration onset rate and peak velocity change for each plunger are shown in Table 4. The onset rate for each cell was calculated as the straight-line slope between two points on a plot of acceleration versus time. The first point is located on the plot at 20% of the peak acceleration. The second point is located at 80% of peak acceleration. The computer program used for these calculations searches for the point at 80% of the peak acceleration level starting at the beginning of the impact profile. The program searches for the point at 20% of peak acceleration starting at the peak acceleration and searching backward in time. For plungers 18 and 101, the onset rate is calculated for the first peak of the acceleration profile even if the maximum acceleration occurs on the second peak (see page 22 in Appendix A for an example of a double peak).

The velocity change is calculated by integrating the Z axis acceleration and tabulating the peak velocity so obtained.

Table 4: Onset Rate (O.R.) in G/sec and Velocity Change (V.C.) in ft/sec

PLUNGER	6G		8G		10G		12G		15G		20G	
	Onset Rate	Velocity Change	Onset Rate	Velocity Change	Onset Rate	Velocity Change	Onset Rate	Velocity Change	Onset Rate	Velocity Change	Onset Rate	Velocity Change
18	365	23.7	533	27.4	738	30.6	914	32.8	1298	37.8	X	X
30	194	8.8	306	11.6	414	13.7	589	16.6	771	19.5	1208	24.1
46	313	7.7	466	9.7	700	11.7	878	13.4	1214	15.4	1700	18.1
100	84	0.3	144	12.8	188	15.1	262	17.2	386	19.6	570	23.5
101	122	25.5	222	30.0	307	33.8	384	36.9	543	41.8	X	X
102	83	18.5	119	22.6	165	26.3	230	29.4	319	33.3	529	39.0
103	103	13.6	174	17.4	220	20.3	280	22.8	387	26.3	584	30.8
104	115	15.8	163	18.9	289	22.0	393	24.8	517	28.4	793	33.6
105	124	12.5	231	15.3	316	18.0	416	20.7	572	23.5	869	27.6
106	132	11.4	217	14.1	303	16.5	396	18.6	550	21.5	819	25.3
107	210	9.8	330	11.8	487	13.6	687	15.5	1014	17.6	1470	20.4
108	X	X	1271	3.1	1368	3.7	1983	4.8	2403	5.9	3210	6.8

Rise Time and Pulse Duration for Each Cell

To understand the calculation of rise time and pulse duration, it is helpful to refer to Figure 4:

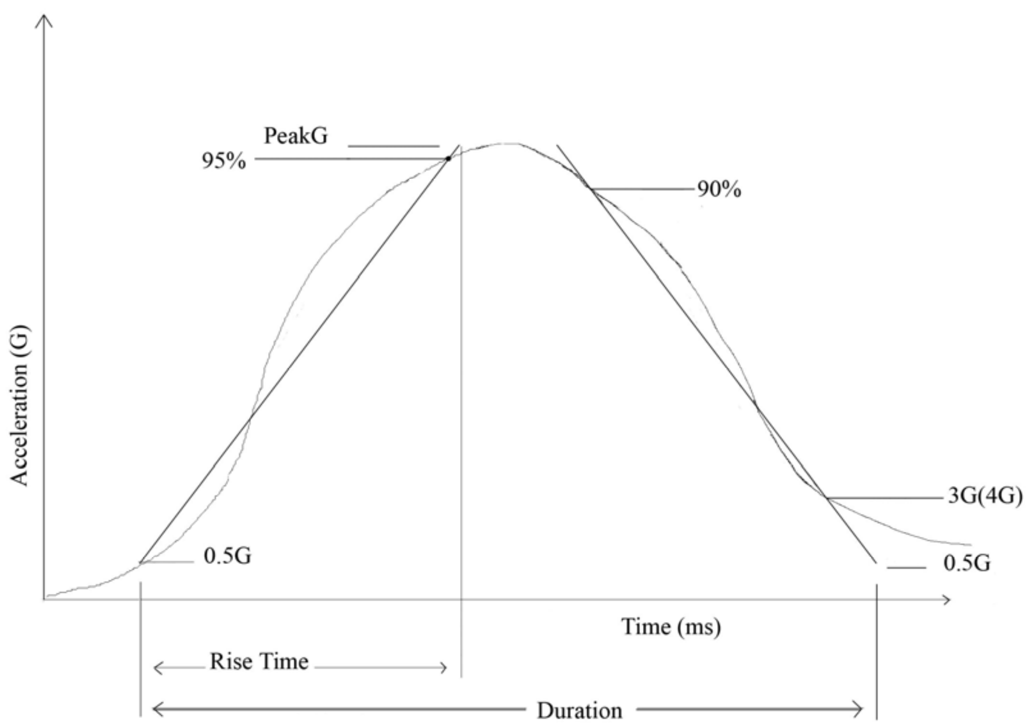

Figure 4: Determination of Rise Time and Duration

A computer program was used to automate calculation of rise time and pulse duration for each cell. This program performed the following steps:

1.) To remove the DC offset from the impact profile, an average is computed for 24 ms starting at the reference mark time. This average is subtracted from the impact profile before computing the rise time and duration.
2.) The time is set to zero at the start of impact. The start of impact is the time on the rising side of the acceleration profile at which the acceleration level is equal to 0.5 G (since no time point is exactly 0.5 G, the closest time point that is less than 0.5 G is used). The acceleration level must be greater than or equal to 0.5 G for 5 consecutive time points.
3.) For the rise time, a line is drawn through the 0.5 G point and the point at 95% of the peak G level on the rising side of the acceleration profile. The line is extended upward to the same acceleration level as the peak acceleration of the profile. The rise time is the difference between the time when the line reaches the peak acceleration level and the time when the acceleration level is 0.5 G. The program searches for the point at 95% of peak acceleration starting at the beginning of the acceleration profile. The program searches for the 0.5 G level starting at the peak acceleration level and searching backward in time.
4.) For the duration, a line is drawn through the point at 90% of the peak acceleration level and the point at 3 G on the falling side of the acceleration profile. The line is extended downward to 0.5 G. The duration is the difference between the start of impact time and the time when the line reaches 0.5 G on the falling side of the acceleration profile. The program searches for the point at 90% of peak acceleration and the point at 3 G starting at the peak acceleration level and searching forward in time. If the peak acceleration level is greater than 12.5 G, then 4 G is used instead of 3 G since at high peak G levels, the acceleration profile often starts to flatten out at greater than 3 G, distorting the calculated duration.

Table 5 shows the rise time and pulse duration for each cell. Pulse duration was not calculated for cells with two acceleration peaks.

Table 5: Rise Time (R.T.) in ms and Pulse Duration (P.D.) in ms

PLUNGER	6G		8G		10G		12G		15G		20G	
	Rise Time	Pulse Duration	Rise Time	Pulse Duration	Rise Time	Pulse Duration	Rise Time	Pulse Duration	Rise Time	Pulse Duration	Rise Time	Pulse Duration
18	37	X	15	X	14	X	14	X	13	X	X	X
30	29	112	27	102	25	107	23	103	21	89	19	87
46	26	79	24	77	21	80	18	78	16	65	15	63
100	70	117	63	106	57	97	47	89	44	81	39	72
101	42	X	38	X	34	X	32	X	29	X	X	X
102	79	162	73	156	66	144	59	137	55	120	45	112
103	67	165	60	152	56	143	53	138	49	117	44	110
104	46	198	42	165	38	147	36	137	32	119	29	111
105	47	145	42	128	39	121	35	115	31	101	29	94
106	49	138	43	120	39	110	35	107	31	91	28	85
107	32	108	26	96	25	90	22	84	21	72	19	66
108	X	X	10	17	9	23	8	25	9	26	9	24

Rise Time and Velocity Change for Each Cell

Table 6 tabulates rise time and velocity change for each cell. While this table provides no new information, it can be useful when evaluating plunger characteristics for a test program.

Table 6: Rise Time (R.T.) in ms and Velocity Change (V.C.) in ft/sec

PLUNGER	6G		8G		10G		12G		15G		20G	
	Rise Time	Velocity Change	Rise Time	Velocity Change	Rise Time	Velocity Change	Rise Time	Velocity Change	Rise Time	Velocity Change	Rise Time	Velocity Change
18	37	23.7	15	27.4	14	30.6	14	32.8	13	37.8	X	X
30	29	8.8	27	11.6	25	13.7	23	16.6	21	19.5	19	24.1
46	26	7.7	24	9.7	21	11.7	18	13.4	16	15.4	15	18.1
100	70	10.3	63	12.8	57	15.1	47	17.2	44	19.6	39	23.5
101	42	25.5	38	30.0	34	33.8	32	36.9	29	41.8	X	X
102	79	18.5	73	22.6	66	26.3	59	29.4	55	33.3	45	39.0
103	67	13.6	60	17.4	56	20.3	53	22.8	49	26.3	44	30.8
104	46	15.8	42	18.9	38	22.0	36	24.8	32	28.4	29	33.6
105	47	12.5	42	15.3	39	18.0	35	20.7	31	23.5	29	27.6
106	49	11.4	43	14.1	39	16.5	35	18.6	31	21.5	28	25.3
107	32	9.8	26	11.8	25	13.6	22	15.5	21	17.6	19	20.4
108	X	X	10	3.1	9	3.7	8	4.8	9	5.9	9	6.8

DISCUSSION

Although there are a total of twelve available plungers, number 102 is used almost exclusively. This is because it induces a dynamic response in humans which is very similar to that induced by an ejection seat rocket.

Examination of Table 5 shows that only plungers 100 and 102 have a nearly half-sine acceleration profile. All the other plungers have a rise time that is much less than one-half the pulse duration.

Table 4 shows that a wide range of acceleration onset rates are obtainable with the available plungers.

Plungers 18 and 101 are normally not used with human subjects due to the double peak in the acceleration profile. The first peak is caused by the plunger entering the water of the cylinder. The second peak is caused by the carriage impacting the bumper at the base of the tower. For the other plungers the impact of the plunger with the water reduces the velocity of the carriage to near zero before the carriage strikes the bumper.

The method used to calculate the rise time of the acceleration profile for each cell in this report is different than that used in the Biodynamics Data Bank for other tests. (The reason will be given shortly). There, the rise time is calculated by taking the average of two time points: one corresponding to the time at which the acceleration profile reaches 90% of peak acceleration and the other corresponding to the time at which the acceleration level falls to 90% of peak acceleration after the peak acceleration is achieved. The rise time is taken as the difference between the time at which the acceleration profile first achieves 0.5G and the time of this calculated average.

Table 7 is a comparison of the rise times for the tests of this study calculated by the method used in the Biodynamics Data Bank (BDB), and the method used in this report for the other tables (VPRO).

Table 7: Rise Times (ms) By Alternative Methods

PLUNGER	6G		8G		10G		12G		15G		20G	
	Biodynamics Data Bank	VPRO	Biodynamics Data Bank	VPRO	Biodynamics Data Bank	VPRO	Biodynamics Data Bank	VPRO	Biodynamics Data Bank	VPRO	Biodynamics Data Bank	VPRO
18	38	37	18	15	16	14	15	14	15	13	X	X
30	30	29	27	27	26	25	25	23	23	21	20	19
46	27	26	25	24	23	21	20	18	19	16	18	15
100	73	70	64	63	58	57	53	47	49	44	43	39
101	X	42	43	38	35	34	33	32	31	29	X	X
102	93	79	81	73	73	66	67	59	61	55	54	45
103	70	67	62	60	58	56	55	53	50	49	44	44
104	47	46	43	42	42	38	40	36	36	32	31	29
105	52	47	46	42	42	39	37	35	35	31	31	29
106	51	49	45	43	38	39	34	35	32	31	29	28
107	36	32	33	26	30	25	27	22	25	21	23	19
108	X	X	8	10	8	9	9	8	10	9	14	9

Table 7 shows that there is not much difference in calculated rise time for most cells when comparing the results for the two methods. The greatest difference is for Plunger 102. Figure 5 compares the two methods on a plot of the actual acceleration profile for cell F2.

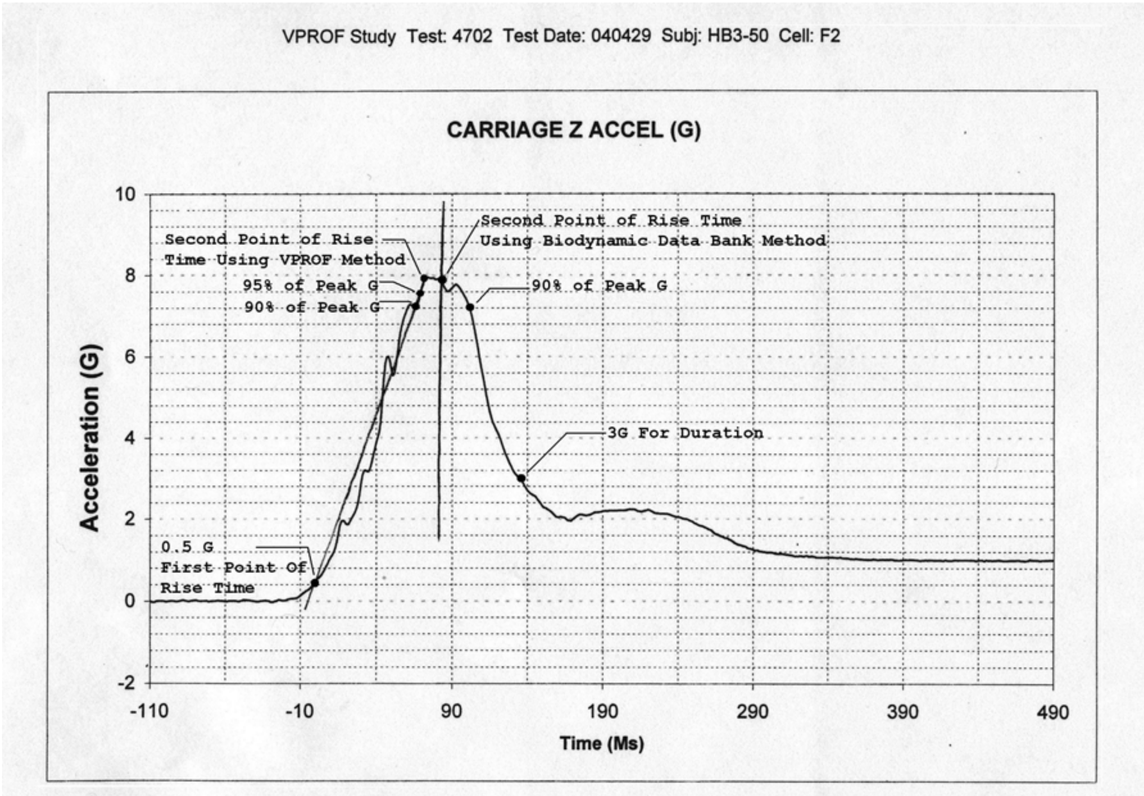

Figure 5: Comparison of Rise Time Calculations

In Figure 5, the tip of the straight line along the leading edge of the acceleration profile marks the point used to calculate the rise time using the method of this report. The vertical straight line on the acceleration profile shows the location of the point used to calculate the rise time by the Biodynamics Data Bank method. Since usually when rise time is specified for a test plan it is a substitute for onset rate, it can be seen that the method used in this report gives a better indication of the slope of the acceleration profile for this plunger. However, if the test plan specifies a half-sine acceleration profile, the Biodynamics Data Bank method would more accurately reflect the desired rise time since a sine curve "levels out" near its peak acceleration. If the pulse shape required in a test plan is sawtooth, trapezoidal, or not specified, the method used in this report is preferred.

CONCLUSIONS

The data collected in this study will enable researchers to quickly determine, by means of easy-to-use tables, if the Vertical Deceleration Tower has the capability to meet the acceleration profile requirements of their test program. The data will be stored in the Biodynamics Data Bank, thereby closing a gap in its coverage of Vertical Deceleration Tower response characteristics.

APPENDIX A

Sample Test Data

VPROF Study Test: 4781 Test Date: 040510 Subj: HB3-50 Wt: 167.0
Nom G: 10.0 Cell: A3 Drop Height: 14'8" PLUNGER 18

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				-128.0	
Impact Rise Time (Ms)				14.3	
Impact Duration (Ms)				274.4	
Velocity Change (Ft/Sec)		30.59			
CARRIAGE X ACCEL (G)	0.01	4.34	-2.49	12.0	347.0
CARRIAGE Y ACCEL (G)	0.00	1.30	-2.38	38.0	32.0
CARRIAGE Z ACCEL (G)	0.00	10.25	-0.71	15.0	350.0
INTEGRATED ACCEL (FT/SEC)	30.04	30.59	-1.34	1.0	327.0
ONSET RATE (G/SEC)		738.11		11.9	3.5

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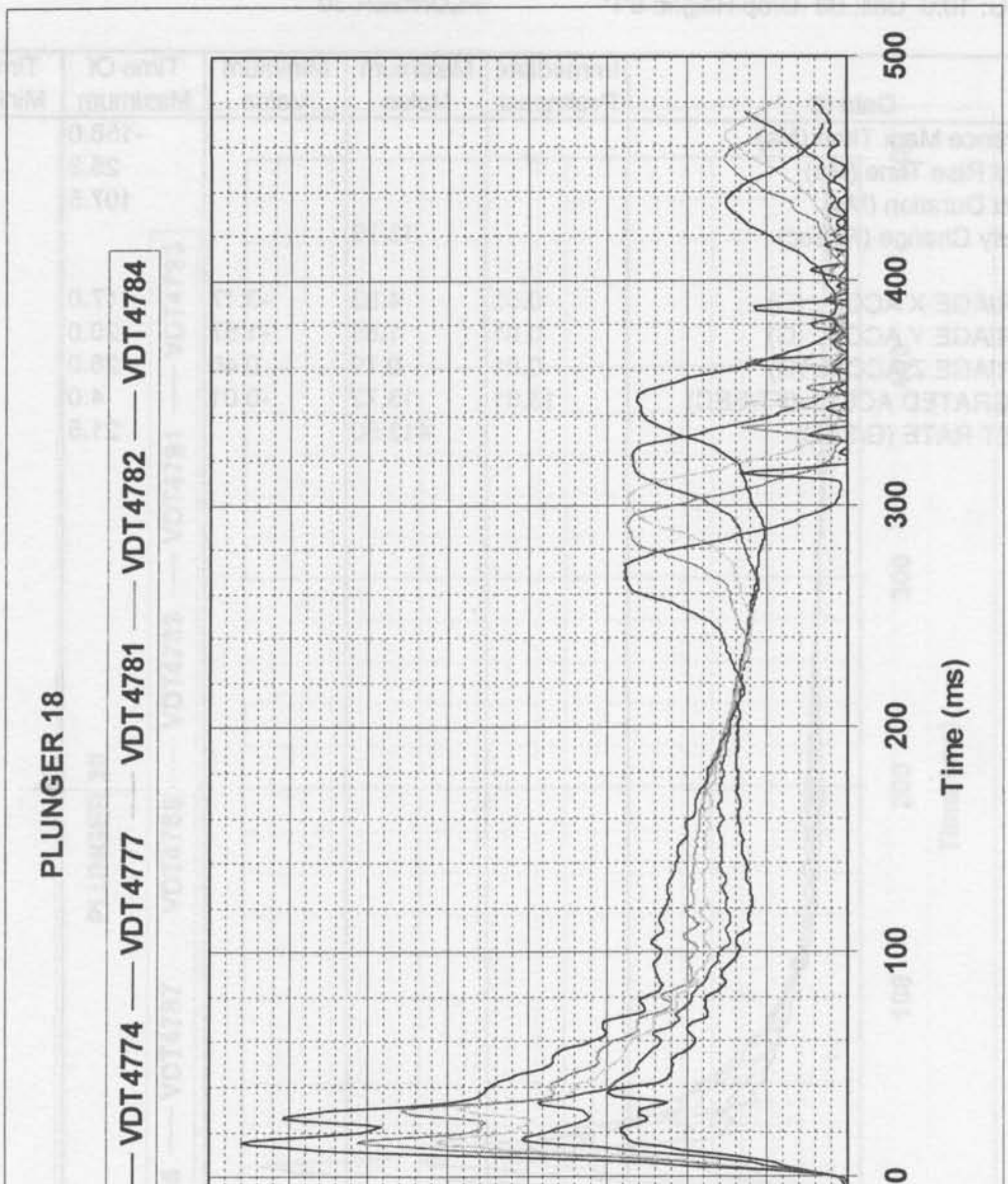
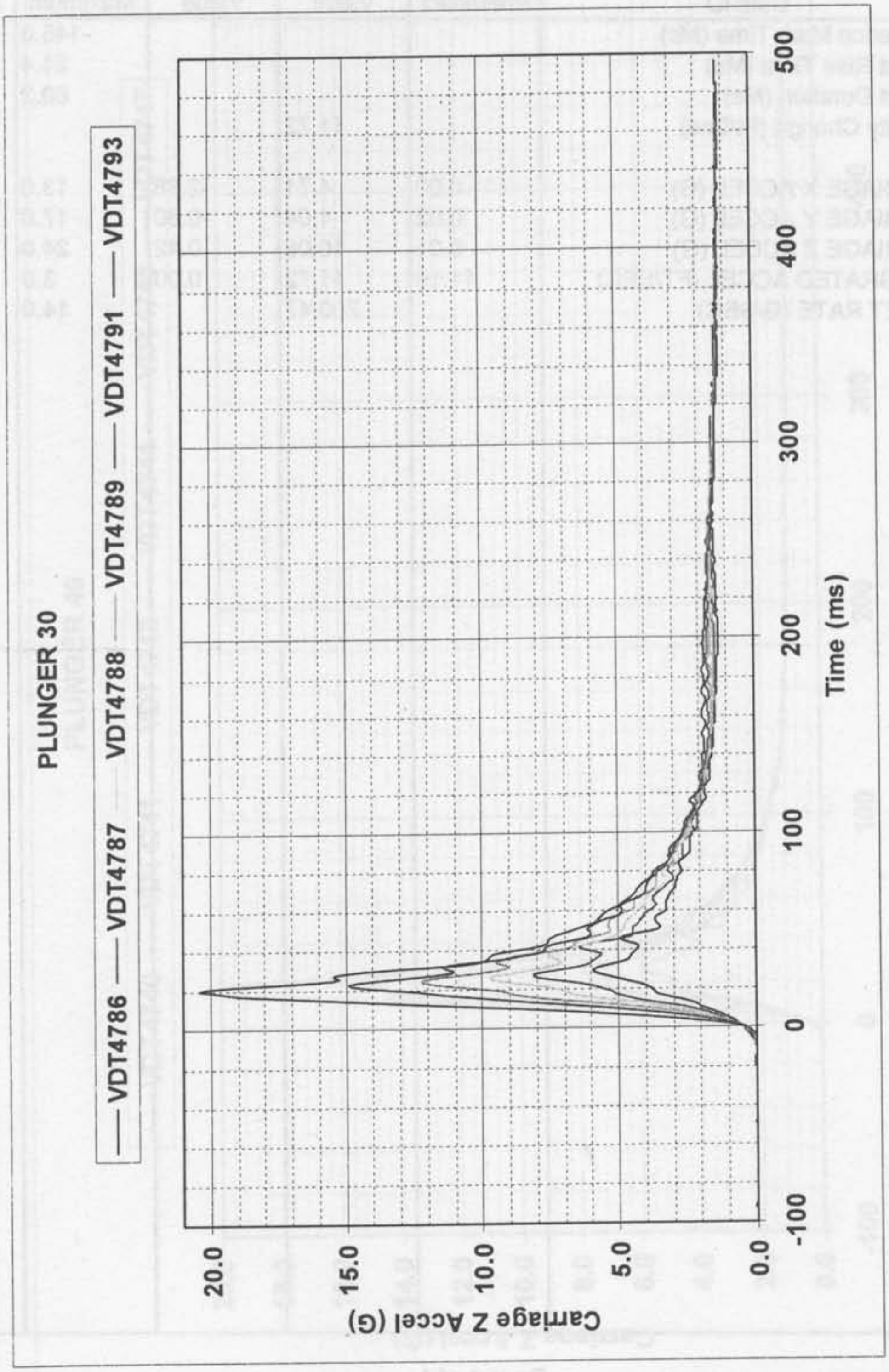

PLUNGER 18
VDT4774
VDT4777
VDT4781
VDT4782
VDT4784
Carriage Z Accel (G)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-100
0
100
200
300
400
500
Time (ms)

VPROF Study Test: 4788 Test Date: 040511 Subj: HB3-50 Wt: 167.0
Nom G: 10.0 Cell: B3 Drop Height: 6'1" PLUNGER 30

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				-158.0	
Impact Rise Time (Ms)				25.3	
Impact Duration (Ms)				107.5	
Velocity Change (Ft/Sec)		13.72			
CARRIAGE X ACCEL (G)	0.03	4.83	-3.17	17.0	22.0
CARRIAGE Y ACCEL (G)	0.01	1.85	-1.57	20.0	42.0
CARRIAGE Z ACCEL (G)	0.01	9.79	0.46	26.0	0.0
INTEGRATED ACCEL (FT/SEC)	13.01	13.72	-0.01	4.0	405.0
ONSET RATE (G/SEC)		413.80		21.5	7.3


PLUNGER 30
VDT4786
VDT4787
VDT4788
VDT4789
VDT4791
VDT4793
Carriage Z Accel (G)
Time (ms)
20.0
15.0
10.0
5.0
0.0
-100
0
100
200
300
400
500

VPROF Study Test: 4742 Test Date: 040505 Subj: HB3-50 Wt: 167.0
Nom G: 10.0 Cell: C3 Drop Height: 3'6" PLUNGER 46

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				-145.0	
Impact Rise Time (Ms)				21.4	
Impact Duration (Ms)				80.2	
Velocity Change (Ft/Sec)		11.72			
CARRIAGE X ACCEL (G)	0.00	4.71	-2.38	13.0	18.0
CARRIAGE Y ACCEL (G)	0.02	1.04	-0.80	17.0	33.0
CARRIAGE Z ACCEL (G)	0.01	10.08	0.42	24.0	0.0
INTEGRATED ACCEL (FT/SEC)	11.16	11.72	0.00	3.0	436.0
ONSET RATE (G/SEC)		700.47		14.0	5.3

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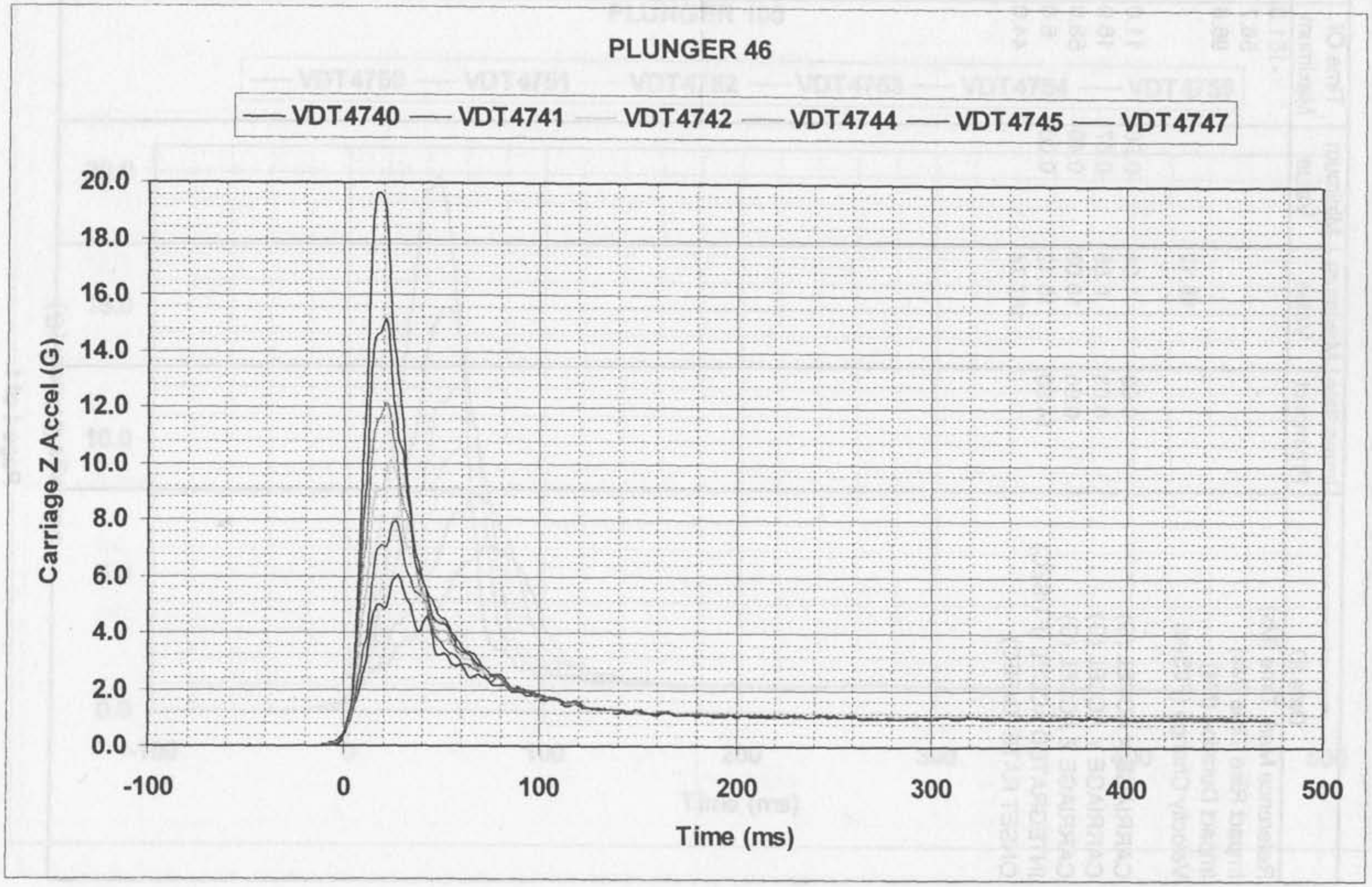
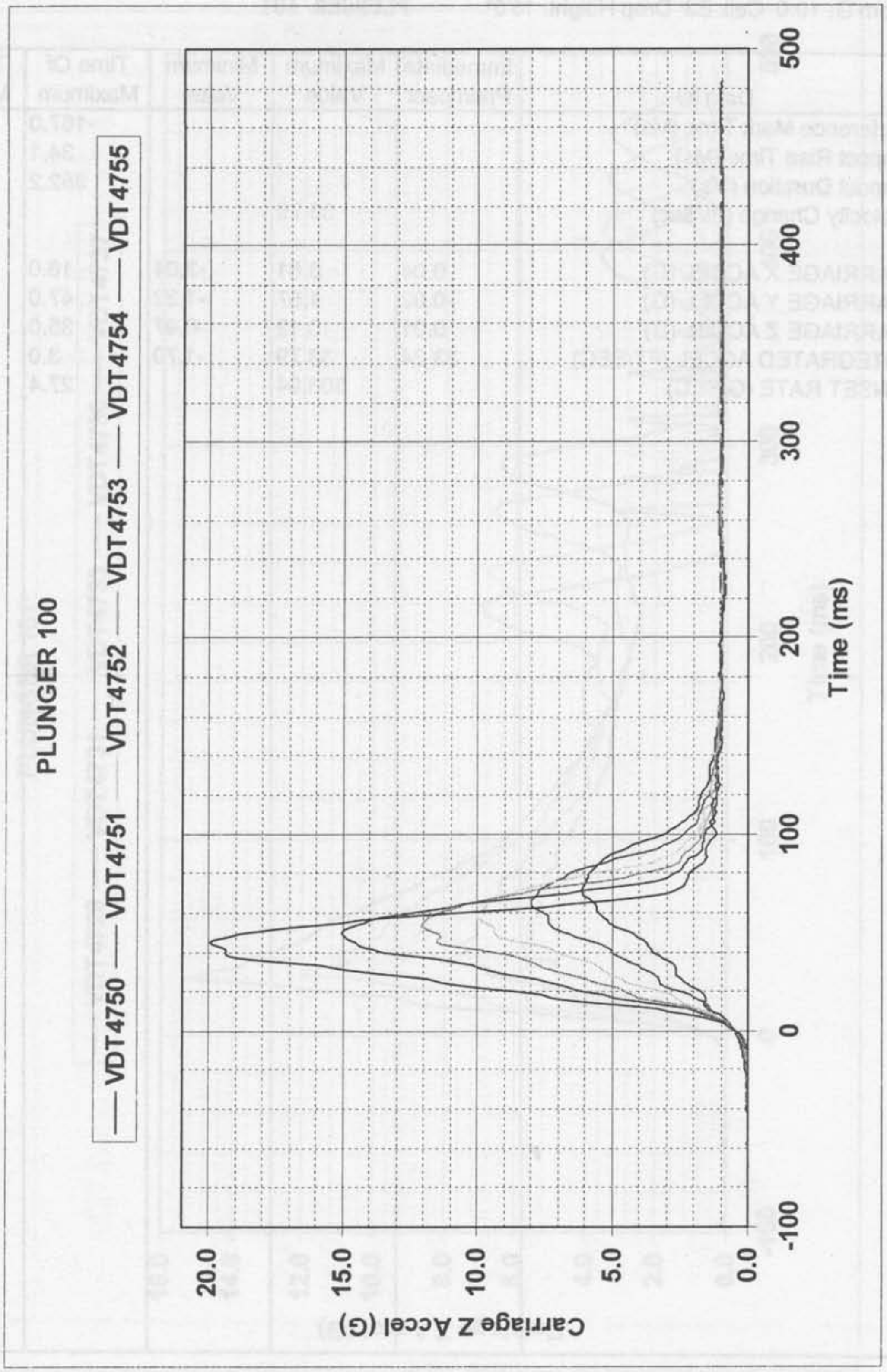

PLUNGER 46
VDT4740
VDT4741
VDT4742
VDT4744
VDT4745
VDT4747
Carriage Z Accel (G)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-100
0
100
200
300
400
500
Time (ms)

VPROF Study Test: 4752 Test Date: 040506 Subj: HB3-50 Wt: 167.0
Nom G: 10.0 Cell: D3 Drop Height: 3'11" PLUNGER 100

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				-151.0	
Impact Rise Time (Ms)				56.7	
Impact Duration (Ms)				96.6	
Velocity Change (Ft/Sec)		15.12			
CARRIAGE X ACCEL (G)	-0.03	1.04	-0.96	11.0	33.0
CARRIAGE Y ACCEL (G)	0.03	0.55	-0.67	16.0	58.0
CARRIAGE Z ACCEL (G)	0.06	10.03	0.49	58.0	0.0
INTEGRATED ACCEL (FT/SEC)	14.60	15.12	0.00	6.0	362.0
ONSET RATE (G/SEC)		187.74		44.0	11.9


PLUNGER 100
VDT4750
VDT4751
VDT4752
VDT4753
VDT4754
VDT4755
Carriage Z Accel (G)
Time (ms)
20.0
15.0
10.0
5.0
0.0
-100
0
100
200
300
400
500

VPROF Study Test: 4733 Test Date: 040505 Subj: HB3-50 Wt: 167.0
Nom G: 10.0 Cell: E3 Drop Height: 18'0" PLUNGER 101

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				-167.0	
Impact Rise Time (Ms)				34.1	
Impact Duration (Ms)				352.2	
Velocity Change (Ft/Sec)		33.79			
CARRIAGE X ACCEL (G)	0.04	3.61	-3.04	16.0	297.0
CARRIAGE Y ACCEL (G)	-0.02	1.57	-1.32	47.0	40.0
CARRIAGE Z ACCEL (G)	0.01	10.12	-0.97	35.0	301.0
INTEGRATED ACCEL (FT/SEC)	33.24	33.79	-1.70	3.0	270.0
ONSET RATE (G/SEC)		306.94		27.4	7.6

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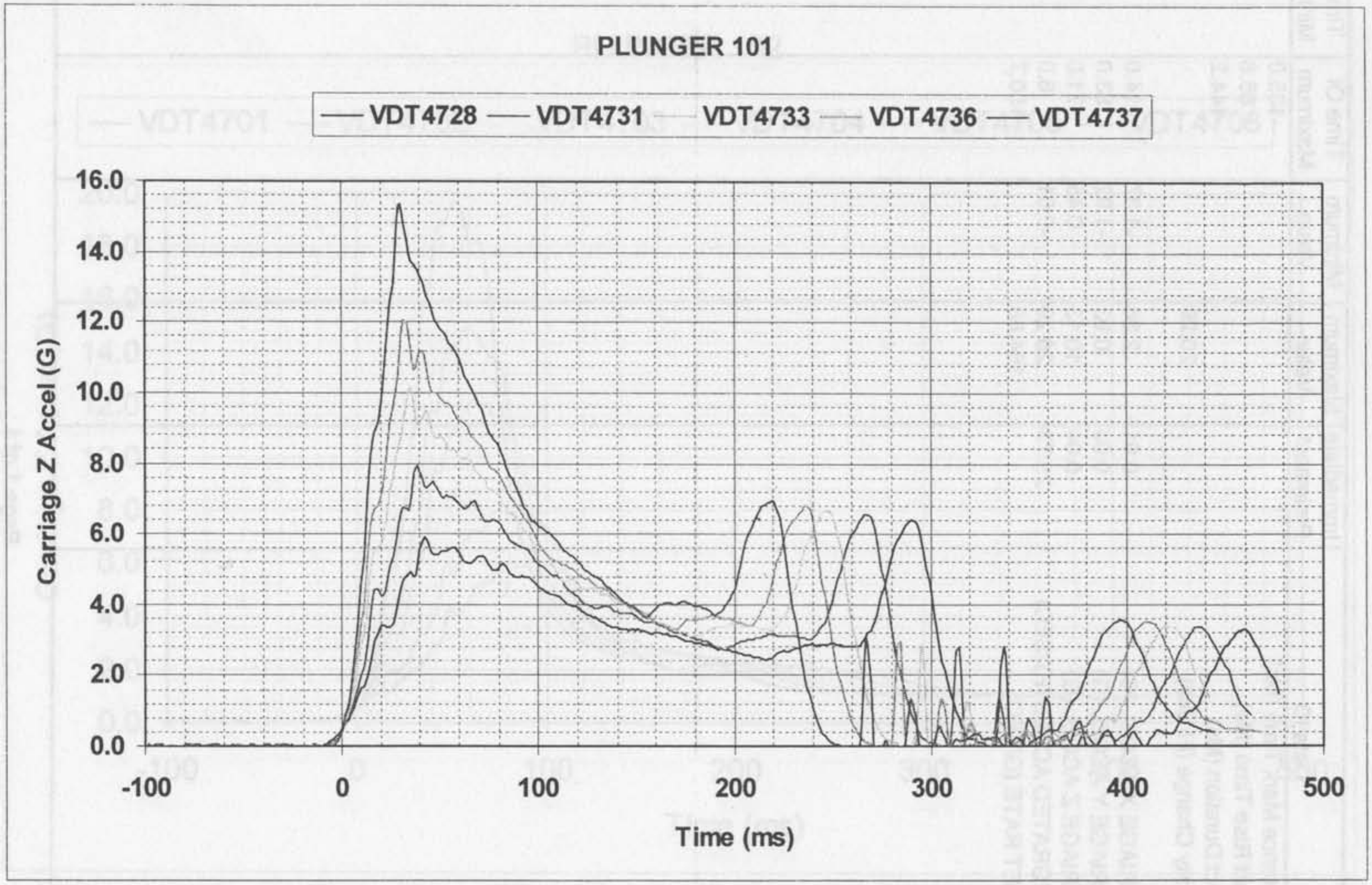
PLUNGER 101
VDT4728
VDT4731
VDT4733
VDT4736
VDT4737
Carriage Z Accel (G)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-100
0
100
200
300
400
500
Time (ms)

VPROF Study Test: 4703 Test Date: 040429 Subj: HB3-50 Wt: 167.0
Nom G: 10.0 Cell: F3 Drop Height: 11'6" PLUNGER 102

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				-135.0	
Impact Rise Time (Ms)				65.8	
Impact Duration (Ms)				144.2	
Velocity Change (Ft/Sec)		26.29			
CARRIAGE X ACCEL (G)	-0.01	2.36	-1.37	14.0	19.0
CARRIAGE Y ACCEL (G)	0.00	0.93	-1.92	83.0	59.0
CARRIAGE Z ACCEL (G)	0.04	10.13	0.45	71.0	0.0
INTEGRATED ACCEL (FT/SEC)	25.73	26.29	-0.01	8.0	392.0
ONSET RATE (G/SEC)		164.68		50.7	13.7

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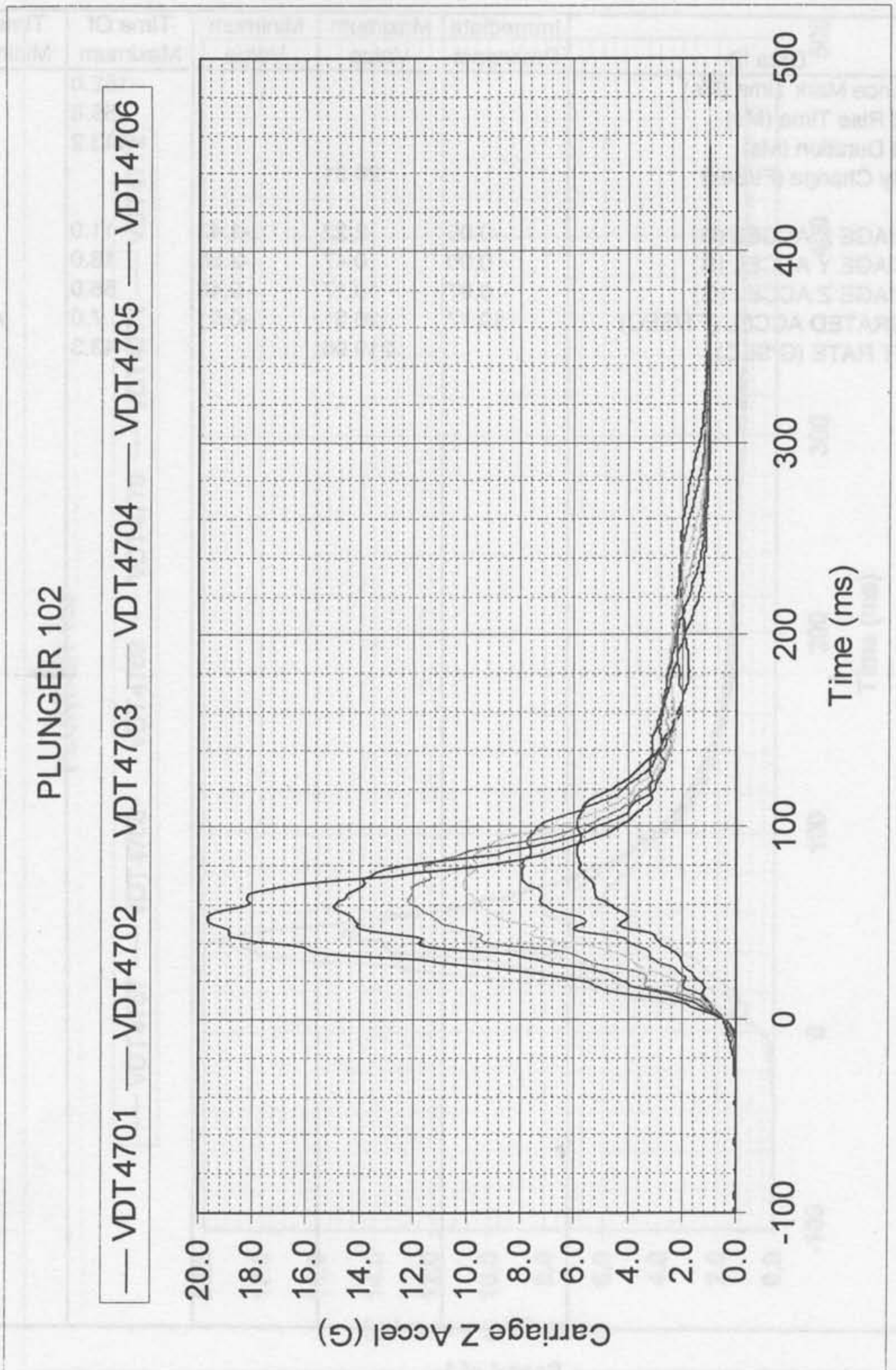
PLUNGER 102
VDT4701
VDT4702
VDT4703
VDT4704
VDT4705
VDT4706
Carriage Z Accel (G)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-100
0
100
200
300
400
500
Time (ms)

VPROF Study Test: 4769 Test Date: 040507 Subj: HB3-50 Wt: 167.0
Nom G: 10.0 Cell: G3 Drop Height: 7'5" PLUNGER 103

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				-152.0	
Impact Rise Time (Ms)				55.8	
Impact Duration (Ms)				143.2	
Velocity Change (Ft/Sec)		20.31			
CARRIAGE X ACCEL (G)	-0.05	2.22	-1.43	11.0	16.0
CARRIAGE Y ACCEL (G)	0.00	0.47	-2.35	18.0	59.0
CARRIAGE Z ACCEL (G)	0.07	10.17	0.48	56.0	0.0
INTEGRATED ACCEL (FT/SEC)	19.77	20.31	-0.01	7.0	417.0
ONSET RATE (G/SEC)		219.96		43.3	15.6

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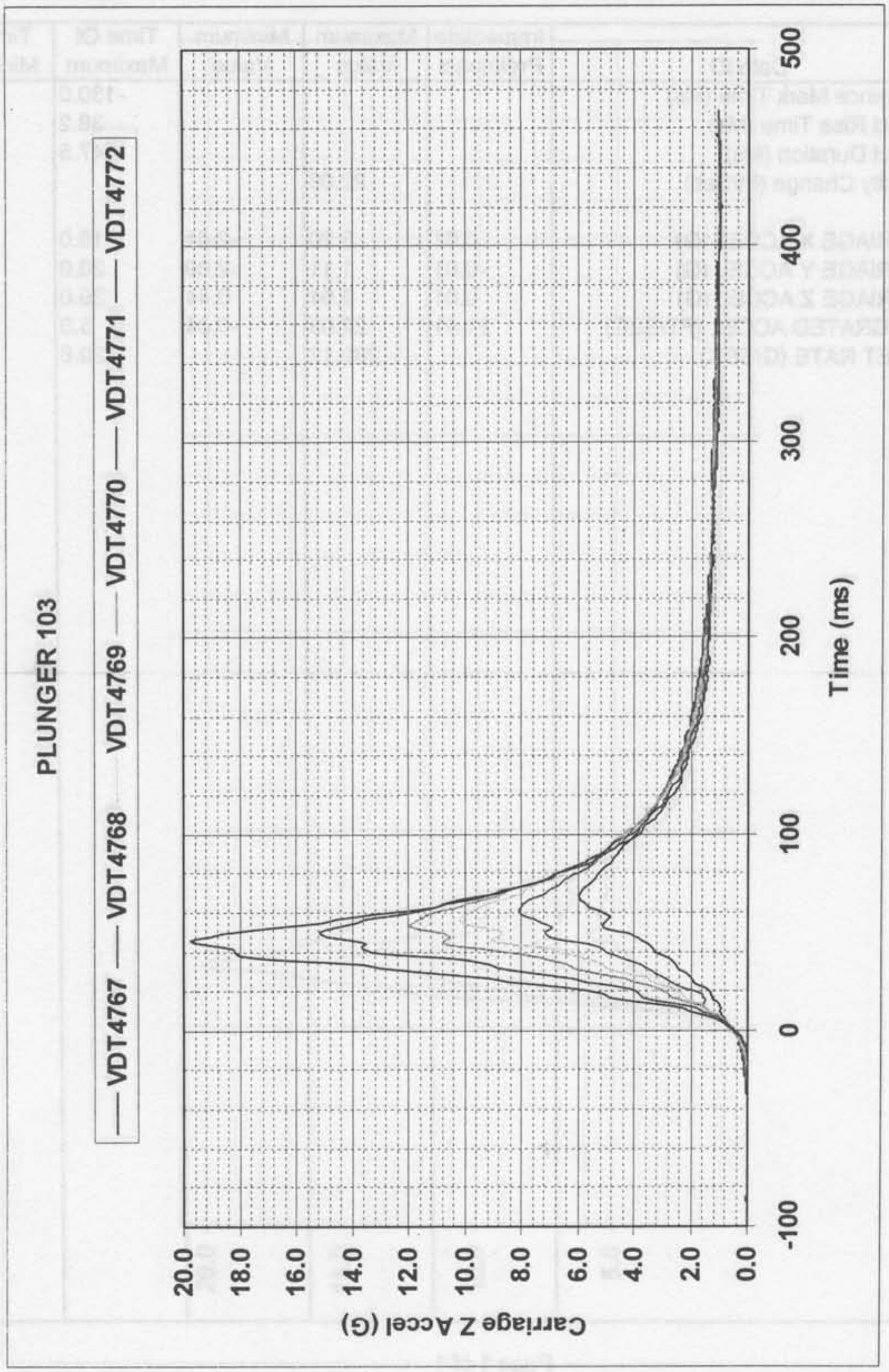
PLUNGER 103
VDT4767
VDT4768
VDT4769
VDT4770
VDT4771
VDT4772
Carriage Z Accel (G)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-100
0
100
200
300
400
500
Time (ms)

VPROF Study Test: 4761 Test Date: 040507 Subj: HB3-50 Wt: 167.0
Nom G: 10.0 Cell: H3 Drop Height: 9'9" PLUNGER 104

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				-130.0	
Impact Rise Time (Ms)				38.2	
Impact Duration (Ms)				147.5	
Velocity Change (Ft/Sec)		22.03			
CARRIAGE X ACCEL (G)	0.01	3.20	-2.04	16.0	21.0
CARRIAGE Y ACCEL (G)	-0.01	1.11	-2.09	20.0	53.0
CARRIAGE Z ACCEL (G)	0.01	9.94	0.44	39.0	0.0
INTEGRATED ACCEL (FT/SEC)	21.41	22.03	-0.04	5.0	374.0
ONSET RATE (G/SEC)		289.12		29.6	8.9

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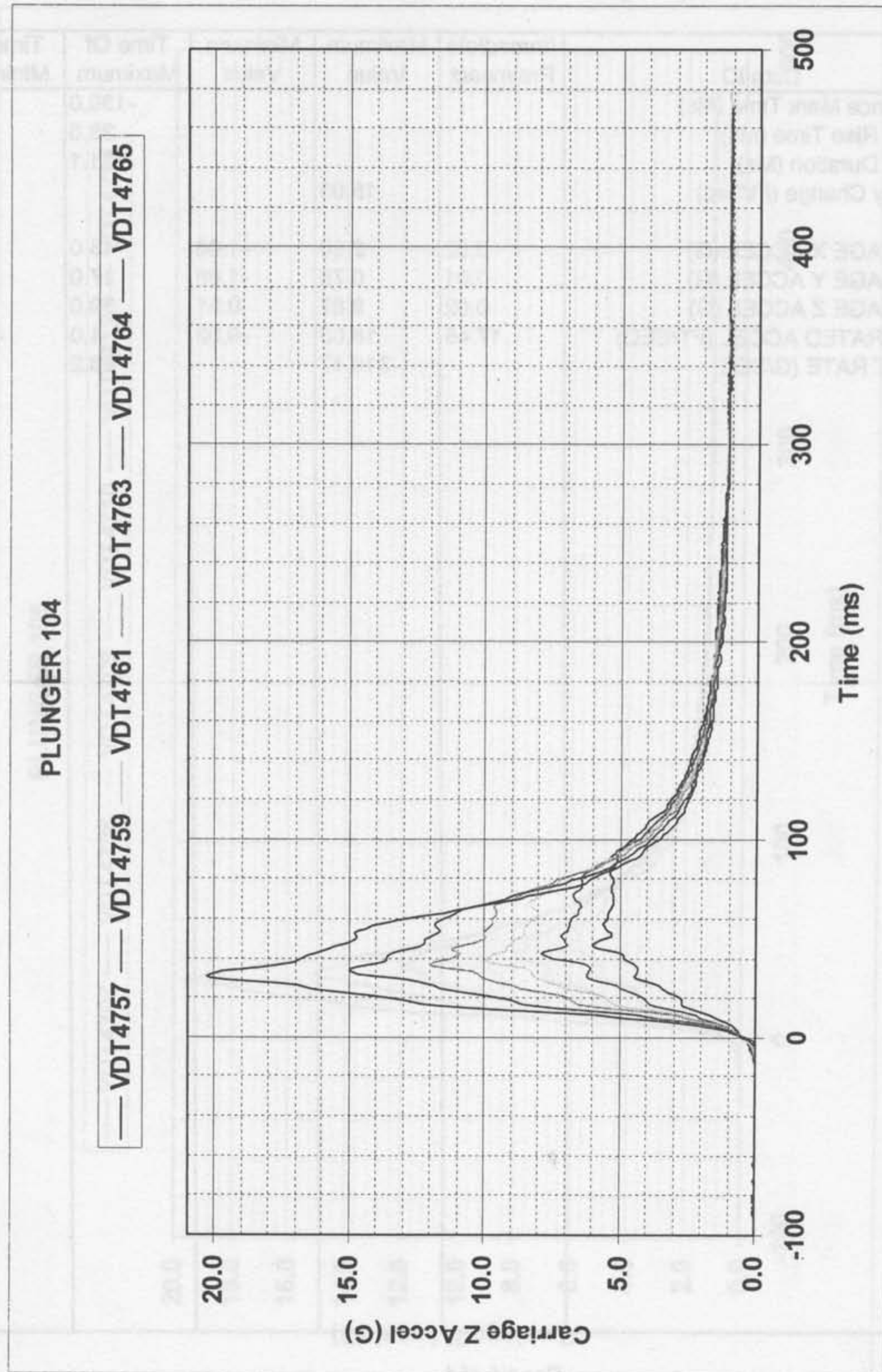
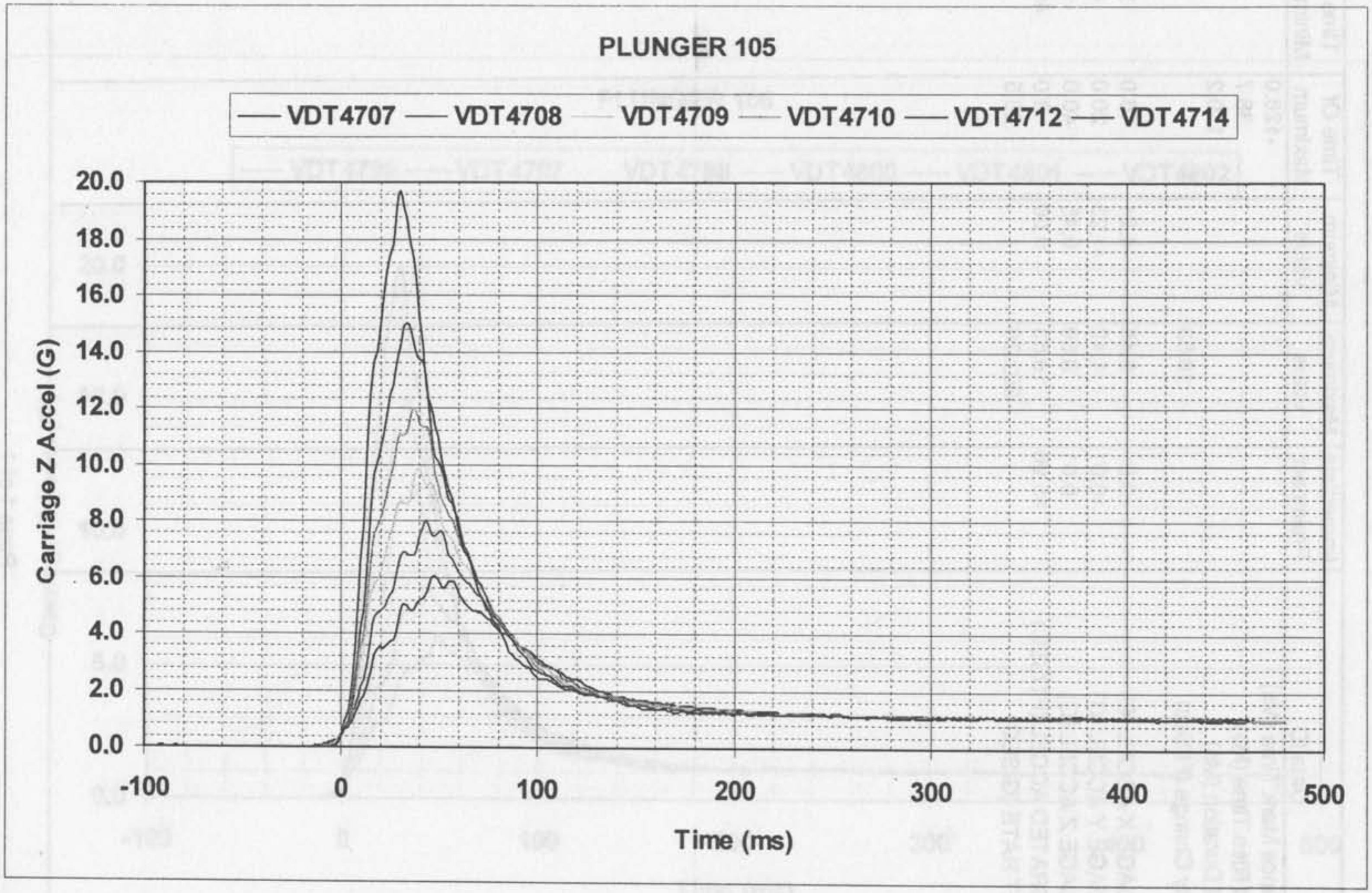


PLUNGER 104
VDT4757
VDT4759
VDT4761
VDT4763
VDT4764
VDT4765
Carriage Z Accel (G)
20.0
15.0
10.0
5.0
0.0
Time (ms)
-100
0
100
200
300
400
500

VPROF Study Test: 4709 Test Date: 040429 Subj: HB3-50 Wt: 167.0
Nom G: 10.0 Cell: I3 Drop Height: 6'6" PLUNGER 105

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				-130.0	
Impact Rise Time (Ms)				38.6	
Impact Duration (Ms)				121.1	
Velocity Change (Ft/Sec)		18.03			
CARRIAGE X ACCEL (G)	0.02	2.50	-1.06	13.0	34.0
CARRIAGE Y ACCEL (G)	0.01	0.76	-1.66	17.0	49.0
CARRIAGE Z ACCEL (G)	0.02	9.87	0.51	39.0	0.0
INTEGRATED ACCEL (FT/SEC)	17.45	18.03	-0.02	4.0	448.0
ONSET RATE (G/SEC)		316.17		26.2	7.4



PLUNGER 105
VDT4707
VDT4708
VDT4709
VDT4710
VDT4712
VDT4714
Carriage Z Accel (G)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-100
0
100
200
300
400
500
Time (ms)

VPROF Study Test: 4798 Test Date: 040513 Subj: HB3-50 Wt: 167.0
Nom G: 10.0 Cell: J3 Drop Height: 5'5" PLUNGER 106

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				-128.0	
Impact Rise Time (Ms)				38.7	
Impact Duration (Ms)				110.2	
Velocity Change (Ft/Sec)		16.53			
CARRIAGE X ACCEL (G)	-0.01	5.45	-4.21	16.0	22.0
CARRIAGE Y ACCEL (G)	-0.01	1.42	-1.23	20.0	48.0
CARRIAGE Z ACCEL (G)	0.01	9.89	0.45	40.0	0.0
INTEGRATED ACCEL (FT/SEC)	15.96	16.53	0.00	3.0	450.0
ONSET RATE (G/SEC)		302.76		26.5	6.9

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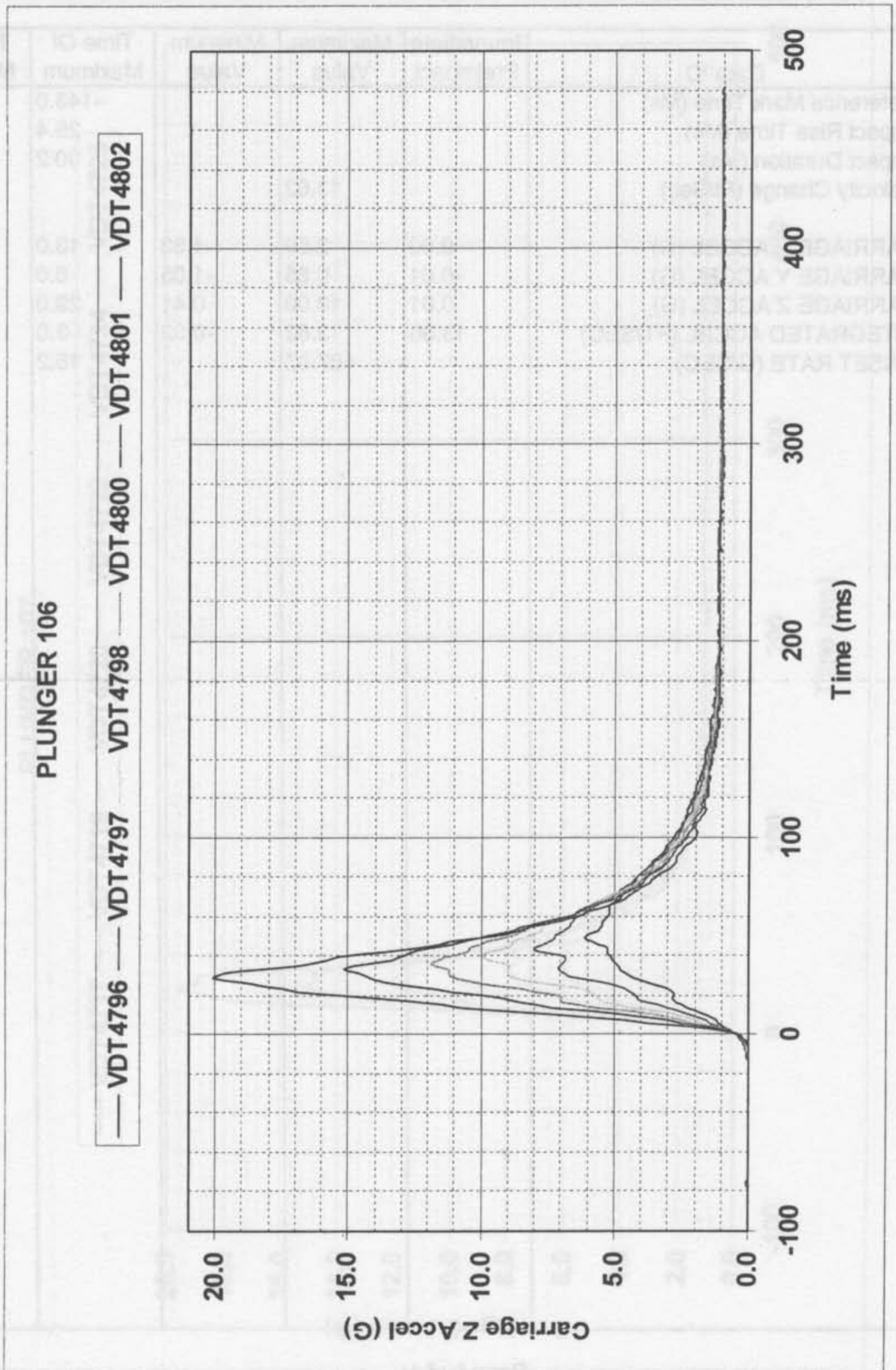
PLUNGER 106
VDT4796
VDT4797
VDT4798
VDT4800
VDT4801
VDT4802
Carriage Z Accel (G)
20.0
15.0
10.0
5.0
0.0
-100
0
100
200
300
400
500
Time (ms)

VPROF Study Test: 4720 Test Date: 040503 Subj: HB3-50 Wt: 167.0
Nom G: 10.0 Cell: K3 Drop Height: 3'9" PLUNGER 107

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				-143.0	
Impact Rise Time (Ms)				25.4	
Impact Duration (Ms)				90.2	
Velocity Change (Ft/Sec)		13.62			
CARRIAGE X ACCEL (G)	0.00	2.59	-1.33	13.0	33.0
CARRIAGE Y ACCEL (G)	-0.01	0.85	-1.05	8.0	32.0
CARRIAGE Z ACCEL (G)	0.01	10.00	0.41	29.0	0.0
INTEGRATED ACCEL (FT/SEC)	13.06	13.62	-0.02	3.0	268.0
ONSET RATE (G/SEC)		487.07		18.2	5.9

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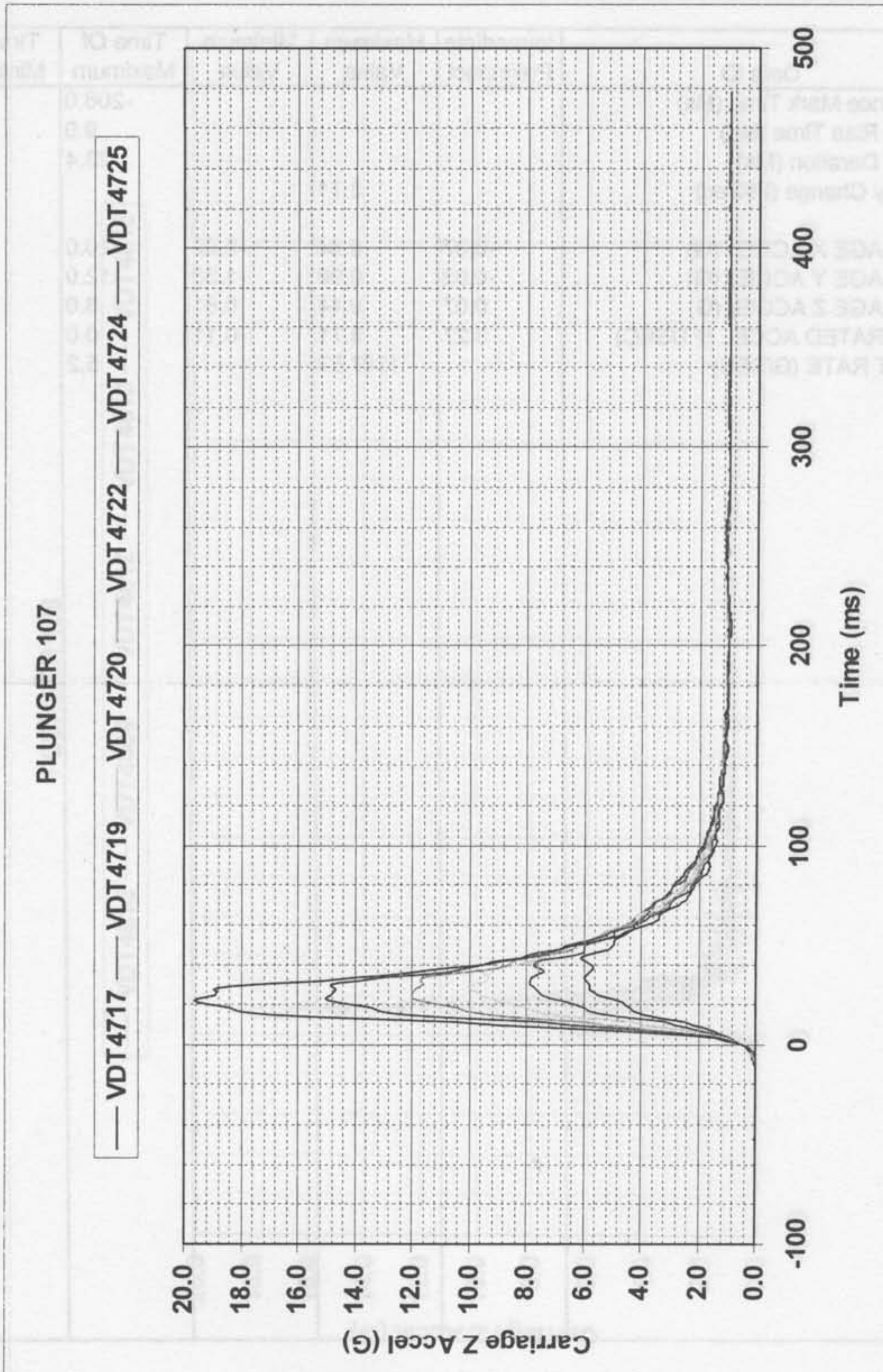

PLUNGER 107
VDT4717
VDT4719
VDT4720
VDT4722
VDT4724
VDT4725
Carriage Z Accel (G)
Time (ms)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-100
0
100
200
300
400
500

VPROF Study Test: 4806 Test Date: 040513 Subj: HB3-50 Wt: 167.0
Nom G: 6.0 Cell: L3 Drop Height: 0'1" PLUNGER 108

Data ID	Immediate Preimpact	Maximum Value	Minimum Value	Time Of Maximum	Time Of Minimum
Reference Mark Time (Ms)				-206.0	
Impact Rise Time (Ms)				9.0	
Impact Duration (Ms)				23.4	
Velocity Change (Ft/Sec)		3.71			
CARRIAGE X ACCEL (G)	-0.07	5.64	-3.92	10.0	15.0
CARRIAGE Y ACCEL (G)	-0.02	0.99	-1.33	12.0	28.0
CARRIAGE Z ACCEL (G)	0.07	9.44	0.81	8.0	61.0
INTEGRATED ACCEL (FT/SEC)	3.27	3.71	-0.11	0.0	53.0
ONSET RATE (G/SEC)		1367.57		5.2	1.0

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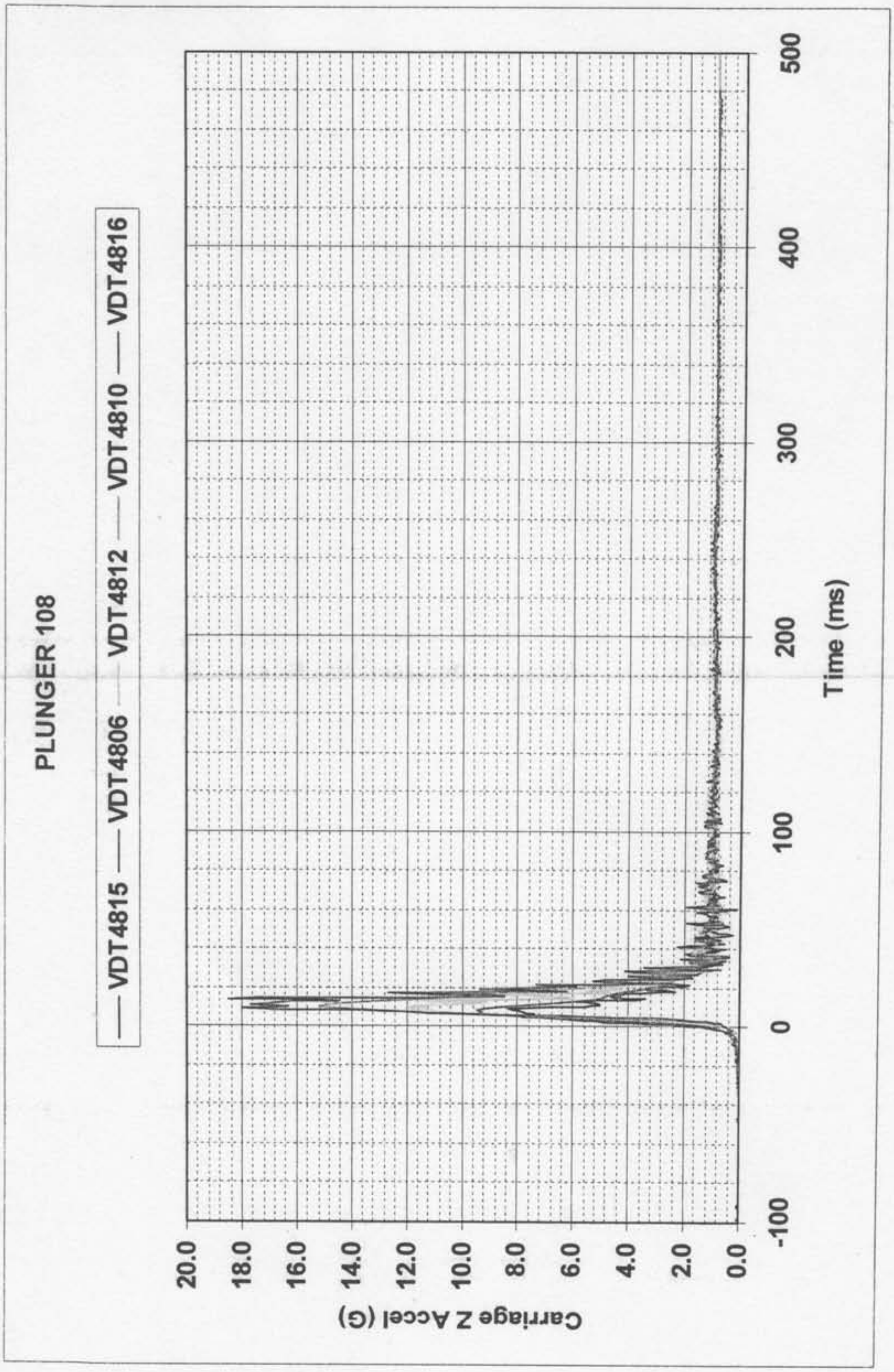
PLUNGER 108
VDT4815
VDT4806
VDT4812
VDT4810
VDT4816
Carriage Z Accel (G)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-100
0
100
200
300
400
500
Time (ms)